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PHYSIOLOGICAL MEASURES AND MENTAL-STATE ASSESSMENT

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I have been to a number of conferences on work load assessment in recent years. A major focus in these meetings has been on the upper end of the work load continuum. How can we evaluate, how can we reduce, how can we cope with unusually high work load levels? It is our contention that, except for relatively few situations, the real danger lies at the other end of the continuum, namely, what can we do to maintain an acceptable level of vigilance, alertness, attention, on the part of our complex equipment operator. Within this context, we immediately have to think of "mental states" (states of the organism) to make sense of work load assessment issues.

Pilots no longer fly aircraft; they exert supervisory control over a computer system which generally does a more satisfactory job of maneuvering the aircraft from take-off to landing than a human pilot. These systems, however, occasionally break down, and the pilot has to assume responsibility for flying the aircraft. How do we maintain the pilot's proficiency to fly the aircraft? How do we assure ourselves that the pilot is attentively monitoring equipment to detect and correct equipment malfunction? How do we keep him scanning the skies and his radar display to assure himself that he or someone else is not on a collision course with him/her?

We know that man's ability to monitor equipment that seldom breaks down is, at best, mediocre. What can we do to enhance vigilance? What can we do to detect or avoid vigilance decrements?

Vigilance, arousal, alertness, and attention are all concepts that touch on the issue of mental state assessment. How have psychologists traditionally gone about the task of mental state assessment? We ask subjects to rate or otherwise evaluate their state. We monitor aspects of performance and infer mental state from performance, or we can monitor physiological measures and infer mental state from the outputs of physiological sensors, or we can look at a combination of performance and physiological measures.

As a human psychophysiological, I am interested in using physiological measures to allow me to make inferences about our subject's level of alertness, about cognitive operations used to solve problems, and about affective states. In the present context, I am interested in the impact of these mental states on performance. I am concerned with using physiological measures to predict and, hopefully, abort performance decrements or human error. I, thus, would like to have some valid measures of performance.

I am less concerned with, and interested in subjective reports, with what the subject verbalizes about either his level of alertness or ability to perform. As one trained in clinical psychology, I have little faith in what we say about issues, such as alertness and ability to perform. Human error is a major cause of all accidents. I am certain that most persons involved in an accident did not do so voluntarily. We have accidents

because our judgment about our ability to perform is in error!

We have approximately 35,000 fatal automobile accidents each year, and probably ten times that many non fatal accidents. Most of these accidents are not single, but multiple vehicle accidents. Although I object to people injuring themselves, for both humanitarian and health care cost containment issues, the courts apparently are ambivalent on this issue. On the one hand, they have declared laws insuring the wearing of safety helmets on the part of motorcyclists invalid, while on the other, they have passed laws to encourage the use of seat belts.

I object vehemently to incapacitated drivers engaging in involuntary manslaughter, or seriously injuring innocent motorists. If the law does not allow me to protect a fool from himself, it is reasonably positive about attempting to protect others from the fool (e.g., drunk driving laws). My ideal is to have each vehicle equipped with a red light that warns others when the driver is not performing safely. One can then pull off to the side of the road until the danger has passed. If the courts don't want to protect people from foolishly killing themselves, perhaps they can be encouraged to help assure some increment in safety for the innocent bystander.

How might we go about this task of evaluating mental state to reduce mayhem on the highway, and to a lesser extent, in the sky? It is our contention that as the task requirements made of drivers or pilots decrease beyond current levels, the likelihood of occurrence of accidents will increase. Although I was unable to find the documentation for the following statement, it is a reasonable one, namely, the likelihood of a driver utilizing cruise control for highway traveling increases the likelihood of his being involved in an accident. The availability of cruise control takes away a number of requirements on the driver, namely, checking his speed, varying pressure on the gas pedal to maintain a desired speed, and, to a lesser extent, checking signs indicating speed limits. The driver has to attend to a more limited set of environmental inputs. If work load falls below a given limit, we suspect that drivers may begin to reduce attention to levels where unusual environmental events may be missed--and accidents occur.

Paradoxically, rather than having more time to devote to visual scanning, steering and braking, taking away the requirement to monitor and control speed leads to a reduction in such behavior. The same situation prevails, we believe, in commercial aircraft, not of the future, but the present. BOAC pilots, as we understand it, spend most of their flights monitoring equipment, rather than being actively engaged in flying the aircraft for which they are responsible. On a minimum number of flights, they are permitted to control the aircraft during take-off, flight, and landing. We suspect that the pilot's ability to detect and correct problems, should they occur, is seriously compromised by making the pilot a monitor of displays, rather than responsible for flying the aircraft.

How can we deal with this problem? Two complementary procedures are envisioned. First, if we can monitor the pilot's level of alertness or attention to his displays, and identify periods where his attention level falls below acceptable limits, we can provide him and others with feedback

about his condition. Much like my warning signal on the top of cars that alerts other drivers that our vehicle is not being safely driven, we would like to warn the pilot, copilot, and other flight personnel when a member of the flight crew's level of alertness to his task falls below acceptable limits. Secondly, we believe such monitoring might be used to determine optimal conditions of pilot-aircraft interaction that will maintain an acceptable level of attention on the part of the flight crew. Thirdly, it could be used in the design of the cockpit of the future.

What should be monitored physiologically to evaluate alertness and attention? We do not believe that a "universal alertness monitor," which tracks physiological systems A, B, C,...N, and uses this information the same way, regardless of who the pilot is, can be designed. There are marked individual differences in physiological system responsiveness, which suggests a monitoring package unique to each individual. We will return to this issue after we explore the issue of monitoring attention. A major attentional component, for the pilot, deals with visual inputs, be they from the instrument panel or the world outside the cockpit. Auditory components, in the form of communication functions, are generally handled by the copilot; however, other auditory inputs fall in the domain of the pilot. We will single out visual input as a component that is most important to pilot function, and one that has the advantage of being able to be monitored remotely. The evaluation of attentional variables suggests that the pilot engage in definable amounts of visual scanning during most portions of the flight. Thus, fixation pause duration suggests itself as an important component. If fixation pauses exceed a specifiable upper limit (during specific flight segments), we suspect that the pilot is no longer "looking," but is "staring" (perhaps vacuously), and not taking in visual information. Pilots should check specific instruments at definable intervals. If the interval between such checks exceeds specifiable limits, we suspect the pilot is no longer flying safely. One can take this issue a step further, and evaluate patterns of instrument checks.

If dwell time on an instrument becomes unusually short, and/or the pilot returns gaze to that instrument again, shortly after having looked at it, one can again infer inefficient search. Neville Moray inferred that this pattern might suggest that the pilot acquired necessary information from an instrument, but forgot the information and had to cross-check. If this occurs "frequently," our pilot is, again, not functioning efficiently.

What other information can we obtain from eyes to monitor attention? As you might expect, I will offer the eye blink as a second variable that may provide us with useful information about visual monitoring ability. We have some information which suggests that in the performance of critical visual tasks, blinks are least likely to occur as the eyes move to the instrument that provides such information, and most likely to occur as gaze returns to a routine area of the display. Our impression, based on data collected in a DC-9 simulator at Langley, suggests that blinks are more likely to be associated with gaze shifts in the vertical, than horizontal plane, and, from other work, we know that they are more likely to be tightly coupled to large amplitude saccades and head movements. We suspect that breakdowns in attention will lead to altered patterns of saccade/blink, head movement/blink activity, and saccade/head movement activity, as well as alterations in the temporal patterning of these actions.

We can, of course, monitor eye closures and their duration. Eyelid closures in excess of .5 sec would index lack of attention to the task at hand. Thus, monitoring aspects of oculomotor activity appears, to us, to be a most reasonable procedure for evaluating changes in visual attention. We have given a few examples of what might, in general, be monitored to evaluate aspect of visual attending.

What about the issue of alertness, a necessary, but not sufficient condition for monitoring attention? We think of alertness as the readiness to respond to unusual events, while attention deals with a focus on specific events.

We, thus, need to be alert to the occurrence of unusual and infrequently occurring events. Man's ability to maintain vigilance or alertness to such events is poor. How might we monitor this ability which may change from moment to moment, as demonstrated by investigators since the 1930's (Bills, 1937 [1]; Williams et al, 1959 [2]). Behavioral measures, in other than laboratory conditions, are of little help, since, in the real world, we never know when an unexpected event is likely to occur. The research strategy recommended by us is to utilize a series of laboratory vigilance tasks and evaluate physiological measures associated with missed signals, as well as false alarms. If one can demonstrate that a given set of physiological measures are correlated with, or predictive of performance drop-out in a variety of vigilance tasks, we would be willing to recommend these measures for the evaluation of attentional attributes under conditions where we have no performance measure against which to compare our physiological measures.

We would like to briefly outline measures that have been used to measure more general and persistent states of alertness. These procedures have generally focused on what happens to such measures as a person goes to sleep.

1) Cardiac activity:

As we move toward sleep, heart rate decreases. Whether that decrease is secondary to a decreases in motor activity, or whether it is only partially dependent or even independent of motor activity is an issue that is still being debated.

Heart rate variability is a derivative measure, and one currently being investigated in a number of laboratories using a variety of measures of such variability. How it relates to the issue of alertness is a question that is in need of investigation.

2) Peripheral vascular activity:

One finds a shift from vasoconstriction to dilation as the person monitored drifts toward sleep. "Spontaneous fluctuations," i.e., non-specific responses that mirror, in wave form, orienting response, might index a change in state, though it has not been systematically studied. One major problem with monitoring such activity is the sensitivity of the measure to even minor movement

artifacts.

3) Skin conductance (resistance or skin potential):

As a subject becomes relaxed, there is a marked decrease in skin conductance, and skin potential drifts from a large, negative value (-70 mv) toward 0, and may even go positive.

A derivative measure of some interest here also deals with "spontaneous fluctuations." The frequency of such responses decreases as one goes toward sleep.

4) Electroencephalography (EEG):

The EEG has been extensively used to define stages of sleep. Unfortunately, less work has been done to evaluate levels of alertness. Two major techniques for utilizing the EEG as a research and clinical tool are in current vogue. The first evaluates alterations in ongoing electrical activity of the brain, and utilizes spectral analysis to define average activity within restricted frequency bands. The second technique evaluates changes in electrical activity produced by specific stimuli. To extract the response to such signals out of the background of ongoing EEG activity, a procedure known as signal averaging is used.

Evaluating EEG spectra associated with altered states of alertness suggests that as a person becomes drowsy, there is initial general enhancement of activity in the alpha frequency band (8-12 Hz), followed by a shift in dominant activity within this band from a higher to a lower frequency. Much of this work has been done under eyes closed conditions, and is thus, probably not directly applicable to the evaluation of attention in visually demanding environments.

A new technology is developing which graphically displays changes in electrical activity over the skull surface. This technique allows one to see dynamic changes in electrical activity during task performance. Its utilization has been hampered by the fact that no procedures for quantifying the data generated have been developed. It is, thus, a technique completely dependent on the observational skill of the user.

Evoked response technology, as applied to the measurement of alertness, has some problems. If we are interested in momentary lapses in alertness, it cannot be used in its present form, since this measure forces us to look at brain responses averaged over a number of stimuli. In general, a minimum of ten trials are necessary to extract the signal of interest out of the background noise. It may be possible to evaluate ERPs to single trials, using template matching or other procedures. If these can be successfully implemented, this objection to the use of ERPs for the evaluation of momentary alterations in alertness may be discarded.

If our concern is with slowly changing states of alertness, this technique appears to be a viable one. One can, as we have described in an earlier presentation at this meeting, evaluate ERPs to either secondary tasks that are imbedded in primary task performance or deal with ERPs to irrelevant stimuli. We would suspect that as alertness lowers, the ability of the brain to time-share information processing capability between primary and secondary or irrelevant task demands is attenuated, and that ERPs to the secondary task are altered, and that their distribution over the head might change.

5) Pupillography:

Changes in pupillary diameter occur not only as a function of changes in light intensity impinging on the eye, but also as a function of task complexity, interest in the material viewed, listened to, or tasted, affective components and states of alertness. Pupil diameter decreases as alertness is lowered. The major problem with utilizing pupillography in a visually demanding environment, is the fact that the amount of light impinging on the eye is continually changing. Since pupillary diameter changes associated with this variable are significantly larger than those associated with alertness, cognitive or affective alterations evaluating the effect of these variables will not be an easy task. Such problems can be solved, but will require major efforts.

6) Oculomotor activity:

Are components of eye movements affected by alterations in alertness? A number of investigators have suggested that alterations in saccadic eye movements occur as a function of "fatigue" or alertness. The alteration is a slowing of peak velocity or average velocity, and is best seen with relatively large amplitude saccades. As we have suggested earlier, saccade frequency may be another indicator, not only of lowering in attention, but alertness, as well. The eye blink is another component of some interest (to us). To the extent that time-on-task effects reflect alterations in alertness, we can demonstrate that in vigilance tasks, there is an increase in average blink closure duration as a function of time-on-task, as well as an increase in long closure durations (closures exceeding 200 msec). Thus, the eye can provide us with useful information, not only with respect to attentional attributes, but alertness, as well.

7) Body movements:

We know of no data dealing with the effect of alterations in alertness on body movements. We suspect that as a person drifts toward drowsiness, he may initially demonstrate increases in body movements, followed by a precipitous decline in such movements, prior to closing the eyes and drowsing off.

These are a few examples of physiological and behavioral variables that should be investigated with respect to their utility in measuring alterations in attention and alertness. We have described a number of measures, and suspect that the best measure of alertness would utilize a combination of such measures. The combination would be individualized to maximize their predictive utility. A lot of research still needs to be done before we achieve this state.

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